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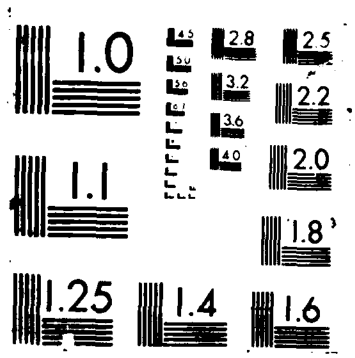
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PHYSIOLOGICAL AND HEMATOLOGICAL RESPONSES OF MATCHED OLDER AND YOUNGER MEN DURING DRY-HEAT ACCLIMATION

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Running Head: Age-Related Responses During Exercise-Heat Acclimation

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de of life.

ABSTRACT

Nine younger and nine older men were matched ($p>0.05$) for body weight, surface area, surface area-to-weight ratio, percent body fat and maximal aerobic power, but differed ($p<0.05$) in age by 25 years and regular weekly aerobic activity. After evaluation in a comfortable environment (22° C, 50% rh), these subjects were concurrently heat acclimated by treadmill walking ($1.56\ m \cdot s^{-1}$, 5% grade) for two 50-min exercise bouts separated by 10-min rest for 10 consecutive days in a hot-dry (T_a=49° C, rh=20%) environment. During the first day of heat exposure, performance time was 27 min longer ($p<0.05$) for the older men while final rectal and skin temperatures and heart rate were lower, and final total body sweat loss higher ($p<0.05$) when compared to the younger men. These physiological advantages for the older men persisted for the first few days of exercise-heat acclimation ($p<0.05$). By the end of acclimation, no physiological or performance time differences were observed between groups ($p>0.05$). Final rated perceived exertion was generally higher ($p<0.05$) for the younger men throughout the acclimation period while final thermal sensation was higher ($p<0.05$) only on the first acclimation day. Sweating sensitivity, esophageal temperature at sweating onset, and the sweating onset time did not differ ($p>0.05$) between groups either pre- or post-acclimation. Both plasma volume and total circulating protein increased ($p<0.05$) from pre- to post-acclimation with no differences ($p>0.05$) between groups. Greater regular weekly aerobic activity for the older men was associated with their better initial performance during exercise in the heat; however, heat acclimation negated this advantage. These findings would challenge the belief that ageing per se is associated with impairment of the thermoregulatory system at least through the fifth decade of life.

Key words: ageing; blood responses; exercise-heat tolerance; heat acclimatization; perceptual responses; sweating responses; temperature regulation

INTRODUCTION

In general, exercise-heat tolerance is reported to be reduced in older adults (8,34). Older adults have been shown to have higher heart rates, mean skin and core temperatures and lower sweat rates than younger adults during exercise in the heat both pre- and post-acclimation (17,34). It has also been reported that older adults start to sweat later and/or sweat less during exercise in the heat than younger adults (16,20). However, in a group of presumably more active elderly women, no differences were noted in their sweating capacity or core temperature at sweat onset compared to younger women during rest or exercise in the heat (7,9).

Several authors (5,29) imply that physically fit older adults appear to have far fewer decrements in performance of exercise in the heat than less fit older adults. In fact, Robinson et al. (29) compared the acclimation responses to exercise in the heat for fit male physiologists during 1942 with the responses of these same individuals some 21 years later. These older men acclimated to exercise in the heat at the same rate and to the same degree as when they were younger (29). However, none of these studies attempted to match older and younger individuals for any important physiological and/or morphological variables. Further, these earlier studies do not answer whether the thermoregulatory system is impaired by age per se or whether the exercise-heat intolerance observed with ageing is more related to other factors such as decreased physical activity and lowered maximal aerobic power (4,19).

Early comparisons between men and women noted that females reacted to exercise in the heat with higher core temperatures and heart rates than males, and lower sweat rates than males both pre- and post-acclimation (35). These physiological differences between genders were more accentuated while subjects were un-acclimated (35). In these experiments by Wyndham et al. (35), male and female subjects were not matched on any physiological or physical factors. In more recent years, two

studies (2.10) have demonstrated that when men and women were comparable with regard to maximal aerobic power. sur· ·area and/or surface area-to-mass ratio. the previously reported sex-related differences in thermoregulatory responses to heat were diminished or eliminated both pre- and post-acclimation. Therefore. it is reasonable to hypothesize that if older and younger males are matched for maximal aerobic power and selected morphological factors. many of the reported differences in heat tolerance to exercise associated with ageing will not be present.

The purpose of this investigation was to examine heat tolerance to exercise. both pre- and post-acclimation. in a younger and older group of men. These two groups were similar with regard to maximal aerobic power and many morphological factors but differed by approximately twenty-five years in age. In addition. the hematological acclimation responses of these same subjects were evaluated both pre- and post-acclimation.

METHODS

Subjects. Nine older males were selected to serve as volunteer subjects after medical screening. In order to match these older individuals with their younger male counterpart for maximal aerobic power and selected morphological factors. we had to evaluate 22 younger subjects. The physical characteristics of the nine younger and nine older subjects who were matched and evaluated during heat acclimation are presented in Table 1. All subjects were totally informed with regard to experimental risk and gave their informed written consent. All of these experiments were conducted between mid-March and mid-April when subjects were not naturally heat acclimated.

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Protocol. Prior to experimental testing in the heat. each subject's percent body fat was determined by hydrostatic weighing and maximal aerobic power ($\dot{V}O_2$ max)

determined by a treadmill running test. The maximal treadmill protocol was progressive in intensity and continuous in nature. The initial treadmill grade was zero. and increased by 2.5% increments for each additional exercise bout. Exercise bouts consisted of running (2.68 or 3.13 $m \cdot s^{-1}$) for 1.5-minute intervals at each treadmill grade. Each subject's running velocity was determined from his heart rate response to a 10-minute warm-up walk (1.56 $m \cdot s^{-1}$ at 10% grade). If the elicited heart rate response equaled or was greater than 145 $b \cdot min^{-1}$, the 2.68 $m \cdot s^{-1}$ velocity was selected for the maximal test. Conventional criteria were employed for determination of $\dot{V}O_2$ max for the 2.68 $m \cdot s^{-1}$ and 3.13 $m \cdot s^{-1}$ tests (21,33).

Subjects were then concurrently heat acclimated by walking on a treadmill at 1.56 $m \cdot s^{-1}$ on a 5% grade for two 50-minute exercise bouts separated by a 10-minute rest period for 10 consecutive days in a hot-dry (T_a=49°C, rh=20%) environment. It was anticipated that this exercise intensity would require about 45% of $\dot{V}O_2$ max for both groups. During testing, subjects wore gym shorts and tennis shoes; ad libitum water drinking was encouraged during most of the acclimation sessions. However, on the first and last acclimation sessions, some water drinking restrictions were enforced because of the need to measure esophageal temperature and control for absorption effects on collected blood samples. All acclimation sessions were individually terminated, if necessary, by predetermined end-points of a heart rate greater than 180 $b \cdot min^{-1}$ for 5 minutes or rectal temperature greater than 39.5°C, physical exhaustion, dizziness, nausea, or dry skin. These 10 heat acclimation sessions were preceded by a comfortable environment (22°C, 50% rh) evaluation of these subjects involving an identical protocol compared to the acclimation sessions to help familiarize subjects with the testing procedures and collect baseline data.

Physiological and perceptual variables. Electrocardiograms were obtained with chest electrodes (CM5 placement) and radio-telemetered to an oscilloscope-

cardiotachometer unit (Hewlett-Packard). Oxygen uptake ($\dot{V}O_2$.1•min^{-1} STPD) was determined by open-circuit spirometry. Subjects breathed via a -way breathing valve (Collins two-way J) and expired gases were collected in 150-liter Douglas bags. Expired gases were analyzed for O_2 and CO_2 concentrations with an electrochemical O_2 analyzer (Applied Electrochemistry S-3 A) and an infrared CO_2 analyzer (Beckman LB-2), respectively. The volume of expired air was measured by a Tissot gasometer. During the $\dot{V}O_2$ max tests, an automated system (Sensormedics Horizon MMC) was used to measure oxygen uptake employing a Hans Rudolph (#2700) breathing valve.

During the comfortable environment evaluation and each acclimation session, core temperature was obtained from a thermistor inserted ~10 cm beyond the anal sphincter and in the esophagus at the level of the heart. Whereas rectal temperature was measured during each of these sessions, esophageal temperature was measured during the comfortable environment evaluation, and the first and last heat acclimation sessions only. Skin temperatures were monitored with a three-point thermocouple skin harness (chest, calf and forearm) and mean weighted skin temperature calculated (3,31). Both rectal temperature and mean skin temperature values were plotted for each subject at two minute intervals using a HP 9825-B computer and HP 9872-C plotter. Local sweating rates ($\dot{m}_s$) from the upper arm were determined by dew point sensors placed on the skin (14). Prior to each test, nude body weight was determined on a K-120 Sauter precision electronic balance (accuracy $\pm$ 10g). Total body sweat loss ($\dot{M}_{sw}$) was calculated from nude body weight changes adjusted for water intake and urine output. Rated perceived exertion using the Borg scale (23) and thermal sensation using a category rating scale (26) were periodically evaluated.

Blood analysis. Venous blood samples were collected from an indwelling teflon catheter placed within a superficial arm vein. Patency was maintained with heparinized saline; the catheter (2 ml) was flushed with 4 ml of blood before each 10 ml sample

was obtained. During the first and last heat acclimation session, resting blood samples were obtained with the subjects in a standing position (for 30 minutes prior to sampling) in an antechamber (T_a=20°C,rh=40%) and exercise blood samples were obtained approximately 25 minutes into each bout while the subjects continued to walk. Triplicate measurements were made of hematocrit, and duplicate measurements were made of all other blood parameters. An automated system was used to measure hemoglobin (Hemoglobinometer, Coulter Electronics) while plasma protein concentration was quantitated with a refractometer (American Optical), and plasma osmolality was measured by vapor pressure method (Wescor, #5500). The relative percent changes in plasma volume were calculated from the appropriate hemoglobin and hematocrit values obtained at rest and during exercise (6). Plasma volumes at rest were estimated from the equation of Allen et al. (1). The remaining plasma volumes were calculated by adjusting these values by the appropriate relative percent change in plasma volume. Total plasma protein was calculated as a product of plasma volume times protein concentration. Venous blood samples were collected only during the first and last heat acclimation sessions.

Statistical analysis. A repeated measures analysis of variance was used to compare the various physiological and hematological response values. If significant F values were found, critical differences were determined by Tukey's procedures. In addition, paired t-tests were used to evaluate differences in the physical characteristics between the older and younger subjects. Statistical significance was accepted at the $p<0.05$ level.

RESULTS

When the physical characteristics of the younger and older men were compared (Table 1), no significant differences ($p>0.05$) were observed between these two groups for body weight (Wt), DuBois surface area (A_D), surface area-to-weight ratio

($A_D \bullet wt^{-1}$), percent body fat (BF), and maximal oxygen uptake ($\dot{V}O_2max$, $l \bullet min^{-1}$ or $ml \bullet kg^{-1} \bullet min^{-1}$). However, these younger and older men did differ ($p<0.05$) in age, height (Ht), maximal heart rate (HRmax), and weekly aerobic activity (Activity). During the comfortable environment and heat acclimation sessions, there were no group differences ($p>0.05$) in the relative exercise intensity (% $\dot{V}O_2max$) associated with treadmill walking at 1.56 $m \bullet s^{-1}$ up a 5% grade (mean ±SD=43.8±5.6%, young: 44.4±8.6%, old).

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Figure 1 contrasts the performance time (min) between the younger and older men for the comfortable environment evaluation (C) and during the 10 days of heat acclimation. During the comfortable environment evaluation, all subjects for both groups (n=7, each group) completed this 120 min exposure. In contrast, performance time for the younger men was lower ($p<0.05$) on the first day of heat acclimation compared to all other acclimation days. No other significant differences ($p>0.05$) were found between any other pairs of acclimation days for the younger men. Performance time did not differ ($p>0.05$) across acclimation days for the older men. When performance time was contrasted between these two groups, the older men averaged 27 min longer exposure on the first day of acclimation ($p<0.05$) while none of the other group comparisons during the remaining days of acclimation differed ($p>0.05$).

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Figure 2 presents the final rectal temperature (T_{re}), final mean-weight skin temperature (T_{sk}), final heart rate (HR) and final total body sweat loss ($\dot{M}_{sw}$) for the younger and older men during the comfortable environment evaluation and 10 days of heat acclimation. For the younger men, final T_{re} decreased ($p<0.01$) from a mean (±SE) value of 39.4 (±0.1)° C for day 1 to 38.7 (±0.2)° C for day 10. For the older

men, final T_{re} decreased ($p<0.05$) from a mean ($\pm$SE) value of 39.0 ($\pm$0.1)° C on day 1 to either 38.4 ($\pm$0.1)° C on day 8 or 38.5 ($\pm$0.1)° C on day 9. For both groups, the T_{re} responses between days 8, 9 and 10 were not significant ($p>0.05$). While final T_{re} did not differ ($p>0.05$) between groups during the comfortable environment evaluation, final T_{re} was higher ($p<0.05$) for the younger men during each of the first four acclimation days; however, no other group differences were found during the remaining acclimation days ($p>0.05$).

Final T_{sk} decreased ($p<0.01$) for the younger men from a mean value of 37.8 ($\pm$0.2)° C on day 1 to 36.7 ($\pm$0.2)° C on day 10. None of the differences in final T_{sk} for the younger men between days 8, 9 and 10 were significant ($p>0.05$). For the older men, final T_{sk} did not differ ($p>0.05$) across acclimation days. During the comfortable environment evaluation, the final T_{sk} did not differ ($p>0.05$) between groups but final T_{sk} was higher ($p<0.01$) for the younger men only during the first three acclimation days.

Final HR decreased ($p<0.05$) for both the younger and older men from mean values of 164 ($\pm$5) $b \bullet min^{-1}$ and 148 ($\pm$5) $b \bullet min^{-1}$ on day 1 to 139 ($\pm$4) $b \bullet min^{-1}$ and 129 ($\pm$5) $b \bullet min^{-1}$ on day 10, respectively. No differences ($p>0.05$) in final HR were observed between days 8, 9 and 10 for both groups. Final HR was higher ($p<0.05$) for the younger men in the comfortable environment and for days 1, 2, 4, 5 and 7 of heat acclimation.

For the younger men, final $\dot{M}_{sw}$ was lower ($p<0.01$) on day 1 of acclimation with a mean value of 581 ($\pm$29) $g \bullet m^{-2} \bullet h^{-1}$ when compared to day 10 (744$\pm$22 $g \bullet m^{-2} \bullet h^{-1}$). No differences in final $\dot{M}_{sw}$ were observed for these younger men during days 8, 9 and 10 of acclimation. Final $\dot{M}_{sw}$ for the older men was not different ($p>0.05$) across acclimation days. While final $\dot{M}_{sw}$ did not differ ($p>0.05$) between groups in the comfortable environment, final $\dot{M}_{sw}$ was higher ($p<0.05$) for the older men during days 1, 2 and 4 of heat acclimation.

While not presented formally, metabolic rate in either watt (W) or $W \cdot m^{-2}$ did not differ ($p>0.05$) between day 1 and day 10 of heat acclimation. Further, there were no differences ($p>0.05$) between groups in metabolic rate on either the first or last acclimation day.

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Figure 3 contrasts the final rated perceived exertion (RPE) and final thermal sensation (TS) between these older and younger men in the comfortable environment and also during the 10 days of acclimation. Both final RPE and final TS did not differ ($p>0.05$) across these 10 acclimation days for either the older or younger men. Final RPE and TS also did not differ ($p>0.05$) between groups in the comfortable environment. However, final RPE was higher ($p<0.05$) for the younger men on all acclimation days except for day 7 ($p=0.06$). While final TS appears higher for the younger men throughout these 10 acclimation days, *it was only statistically higher* ($p<0.05$) on day 1.

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Table 2 shows the mean values (±SE) for sweating sensitivity or the slope of the $\dot{m}_s$-esophageal temperature (T_{es}) relationship, T_{es} at sweating onset (threshold) and the sweating onset time in minutes contrasting these younger and older men on the first and last day of heat acclimation. For the younger men, both the esophageal temperature at sweat onset (threshold) and the sweating onset time (minute) were lower ($p<0.05$) on day 10 compared to day 1. For the older men, the sweating onset time was lower ($p<0.05$) on day 10 compared to day 1. When these older and younger men were compared, no differences ($p>0.05$) were observed for either the slope, threshold or onset time on the first or last day of heat acclimation.

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Table 3 presents a comparison of the hematological data for the younger and older men during the first and last day of heat acclimation. When no group differences (Y-O) were found, the two groups were combined to investigate for other treatment effects (Acclimation and Pre-Post). While no group differences were observed ($p>0.05$) for plasma volume and total circulating protein, both variables increased ($p<0.05$) on the last compared to first day of acclimation. During exercise, plasma volume increased ($p<0.05$) on day 1 and day 10 of acclimation while total circulating protein increased during exercise only on day 1. The percent change in plasma volume from rest to exercise did not differ ($p>0.05$) between groups or with acclimation.

Osmolality was lower ($p<0.05$) for the younger compared to older men on day 1 (pre-acclimation) and on day 10 (post-acclimation). The younger men also displayed lower sodium (Na^+) on day 1 (post-acclimation) and day 10 (post-acclimation) when contrasted to these older men. However, potassium (K^+) did not differ ($p>0.05$) between groups. Osmolality and Na^+ did not differ ($p>0.05$) between da·· 1 and 10 of acclimation, while K^+ was higher ($p<0.05$) on day 10 compared to day 1. For the younger men, osmolality and Na^+ did not differ when the pre and post values were compared on a given acclimation day ($p>0.05$). For the older men, osmolality was higher ($p<0.05$) post- compared to pre-acclimation on day 10 while Na^+ did not differ pre to post on a given acclimation day. Potassium was higher ($p<0.05$) when post values were compared to pre on both the first and last days of acclimation.

DISCUSSION

In the summary to their recent review, Kenney and Gisolfi (19) conclude that "when rigid criteria are applied to the relatively few studies which have addressed the

issue of how age affects temperature regulation, the concept that heat tolerance and thermoregulatory function are compromised with advancing age is not supported. A comprehensive well-controlled study which screens for disease and normalizes for differences in aerobic power, body composition, body weight/surface area ratio, and state of acclimation is required to answer the questions posed at the beginning of this review." By matching the older and younger men in our study for body weight, A_D, $A_D \bullet wt^{-1}$, body fat and $\dot{V}O_2max$ ($l \bullet min^{-1}$ and $ml \bullet kg^{-1} \bullet min^{-1}$), we have attempted to fulfill this requirement through an evaluation of the acute exercise-heat tolerance, rate and degree of heat acclimation for these individuals.

The acute exercise-heat tolerance of these older men was found to be *superior* to that of the younger men. Average performance time was 27 min longer during the first day of exposure to heat for the older men while final T_{re}, T_{sk} and HR were lower, and final $\dot{M}_{sw}$ higher when compared to the younger men. These physiological advantages for the older men generally persisted for the first few days of exercise-heat acclimation. By the end of this 10 day heat acclimation period, no physiological differences or differences in performance time were observed between these two groups. Both groups demonstrated the classical physiological changes associated with acclimation which are plasma volume expansion, heightened sweating response, and lowered HR, T_{re} and T_{sk} during exercise in the heat. The acclimation process was considered virtually complete for both groups by the documentation of non-significant changes in final T_{re}, T_{sk}, HR and $\dot{M}_{sw}$ during the last three days (days 8-10) of the acclimation period.

Our observations of superior physiological performance for the older than younger men during an acute exercise-heat exposure (first day of heat acclimation) are at odds with the reported literature (8,29,34). Physiological performance during the initial day of exercise-heat exposure has been shown to be either the same (29) or poorer (8,34)

for older compared to younger individuals. When physiological responses were con... ..ed post- acclim... ..n. Robinson et al. (29) showed older and younger individuals acclimated to about the same degree which is in agreement with the findings from the present study while. Wagner et al. (34) report the post-acclimation physiological responses to be higher for his older individuals. However, it should be remembered that none of the previously published reports normalized older and younger subjects for any morphological or physical factors and/or maximal aerobic power.

We believe that the initial advantage in physiological performance seen for our older men during the first few days of exercise-heat acclimation was associated with their significantly greater ($p<0.05$) regular weekly aerobic activity (see Table 1). Our older men averaged nearly 20 $mi \bullet wk^{-1}$ more aerobic activity than their younger counterparts. Most authors report that physical training in a cool environment improves exercise-heat tolerance and/or the rate of acclimation (11,12,13,22,27,28). Maintenance of an enhanced sweating response similar to that seen for our older men with little further change during heat acclimation has been reported previously for fit young individuals (11,28). Several authors (13,27,28) suggest that physically trained individuals show many of the characteristics of heat acclimated individuals while performing exercise in the heat and "behaved as though they were acclimated to the heat" (28). Two detailed reviews are available on this subject (12,24). Enhanced regular aerobic activity on the part of our older men certainly appears to have offset any impairment of their thermoregulatory systems, if indeed one believes that ageing per se affects thermoregulation.

Core temperature at sweating onset (sweating threshold) and/or sweating rate have been compared between younger and older individuals during either passive heating (7,16,32) or while exercising in the heat (8,9,20). Sweating rate has been reported to be lower (8,20,29,32,34) or the same (7,9,16) for older compared to younger individuals

while the core t⌐ ¬erature at sweating onset has been generally shown not to differ with ageing (7,9,16). In addition, Hellon and Lind (16) showed that the onset of sweating during passive heating took twice as long (delayed 15 min) for their older compared to younger men. The reduced or "sluggish" sweating response of older individuals has been attributed by some to neural degeneration and/or a decline in the functional ability of their sweat glands (16,32,34).

Regional sweating from the upper arm and the more rapidly responding T_{es} were employed in our study to evaluate sweating sensitivity (slope), T_{es} at sweating onset (threshold) and time of sweat onset (min) on the first and last day of heat acclimation for matched older and younger men (n=4, each group). The T_{es} threshold at sweat onset did not differ between our older and younger men during acute exercise-heat exposure (day 1 of acclimation) which is in agreement with previous reports using T_{re} (7,9,16); however, new findings show no differences between groups after 10 days of heat acclimation. We have also shown that the sweating sensitivity or $\dot{m}_s$:T_{es} response and onset time for sweating do not differ between older and younger men either pre- or post-acclimation. Sweating onset time was reduced for both groups from day 1 to day 10 of acclimation while T_{es} threshold for sweat onset was reduced significantly only for the younger men during acclimation. However, one noticeable difference was that the T_{es} threshold was initially (day 1) somewhat lower (0.20° C) for the older compared to younger men. Reductions in the core temperature threshold at sweat onset and the sweat onset time have been used as classic signs of heat acclimation. Finally, for the first time total sweating loss was shown to be greater (~178 $g \bullet m^{-2} \bullet h^{-1}$) for our older than younger men during acute exercise-heat exposure which in all probability is related to their more regular and intensive weekly aerobic activity. When taken collectively, these findings would challenge the thought that aging per se is related to reduced sensitivity and capacity of the sweating mechanism (8,16,20,29,32).

Our findings also appear worthy of comment concerning the impact that level of aerobic fitness or $\dot{V}O_2max$ has on exercise-heat tolerance. Henane et al. (18) evaluated the sweat loss during passive heating (55° C db, 40° C wb) of six skiers (66.5 ml•kg^{-1}•min^{-1}, $\dot{V}O_2max$) compared to four swimmers (65.8 ml•kg^{-1}•min^{-1}, $\dot{V}O_2max$). The $\dot{V}O_2max$ and A_D•wt^{-1} did not differ between these groups, but the skiers displayed a higher level of heat tolerance, higher sweating rate and were better heat acclimated than the swimmers (18). These authors conclude that the poorer degree of heat acclimation observed in the swimmers could be ascribed to less rise in deep body temperature while training in cold water. Avellini et al. (3) showed that four weeks of training in cold water (20° C) improved $\dot{V}O_2max$ by ~15% but did not enhance exercise-heat tolerance; in fact, final T_{re} and T_{sk} were higher after training than before during exercise in the heat. During training in cold water, T_{re} and $\dot{M}_{sw}$ did not change. These authors conclude that core temperature must increase during exercise training to stimulate sweating in order for physical training to improve exercise-heat tolerance (3). Our older men achieved and/or maintained their level of aerobic fitness through regular physical training while the younger men achieved their aerobic fitness mostly through genetic endowment. When taken collectively, these findings support the contention that $\dot{V}O_2max$ per se may not be as important as the physiological adaptations associated with attaining the fitness level (25). These adaptations may play a vital role in determining exercise-heat tolerance.

Our younger subjects were probably slightly hyperhydrated as suggested by the osmolality and electrolyte data. The ingestion of more hypotonic fluids, as water, would result in this small osmodilution. As hyperhydration does not modify thermoregulatory responses from euhydration levels (30), this small difference did not influence these results. In fact, pre-acclimation the younger subjects, despite lower osmolality, had higher core temperature responses than their older male counterparts.

Finally, the osmolality and electrolyte ⸗ indicate that these subjects maintained a constant hydration status with each of the exercise-heat exposures. Age did not influence the plasma volume expansion associated with heat acclimation, nor the hemodilution associated with treadmill exercise. The heat acclimation resulted in a proportionate increase in plasma and circulating protein (15:1) indicating that the expansion was totally oncotically mediated (15). The hemodilution associated with treadmill exercise was not different between groups. Since the groups were matched for aerobic fitness, this is not surprising as the transcapillary oncotic and hydrostatic pressures would not be expected to be different. Finally, these data indicate that the hemodilution associated with treadmill exercise is less variable post- than pre-acclimation. This observation supports similar findings for upright (bench step) exercise (15).

Final RPE was generally higher for the younger men during these 10 days of heat acclimation. Relative exercise intensity (%$\dot{V}O_2$max) is thought to provide an important sensory cue to RPE (23). However, since %$\dot{V}O_2$max was the same for both groups, the differing RPE values must be attributed to other factors. Except for HR, none of the other physiological responses evaluated in this study are thought to strongly influence RPE (23). When final HR was computed as a percent of maximum HR for both groups during the first and last days of acclimation, none of the differences between groups (83.0% young, 82.7% old, day 1; 70.8% young, 72.3% old, day 10) were significant ($p>0.05$) which suggests that the different RPE values between groups must be associated with other sensory cues which in all probability represent a gestalt related to the overall greater physiological strain for these younger men exercising in the heat. Final TS was seen to be higher for the younger men on the first day of acclimation with a trend for higher values compared to the older men throughout the remaining acclimation period. Thermal sensation is thought to be influenced by T_{sk}.

but also to a lesser degree from other cues such as core temperature (26). Final TS was found to be moderately correlated ($r=0.42$) with final T_{sk} ($p<0.001$) throughout this 10 day acclimation period. Thus, these older men appear to be at a perceptual as well as physiological advantage when compared to the younger man during these exercise-heat exposures.

In conclusion, the greater regular weekly aerobic activity of the older men was probably responsible for the better initial performance of these individuals while exercising in the heat; however, heat acclimation negated this advantage. When taken collectively, these findings would challenge the belief that ageing is associated with impairment of the thermoregulatory system at least through the fifth decade of life. This study demonstrates the importance of aerobic training for middle-age men on their thermoregulatory responses during exercise-heat stress.

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FIGURE LEGENDS

FIG. 1. Comparison of performance time (mean±SE) between the older and younger men during the control (C) day and during each of the 10 exercise-heat acclimation days.

FIG. 2. Comparison of final rectal temperature (T_{re}). mean skin temperature (T_{sk}). heart rate (HR) and total body sweat loss ($\dot{M}_{sw}$) between the older and younger men during the control (C) day and during each of the 10 days of exercise-heat acclimation. Values are the mean±SE.

FIG. 3. Comparison of final rate perceived exertion (RPE) and thermal sensation (TS) between the older and younger men during the control (C) day and during each of the 10 days of exercise-heat acclimation. Values are the mean±SE.

Table 1. PHYSICAL CHARACTERISTICS OF THE YOUNGER AND OLDER SUBJECTS

Group	Age (yr)	Ht (cm)	Wt (kg)	A_D (m^2)	$A_D \bullet wt^{-1}$ ($cm^2 \bullet kg^{-1}$)	BF (%)	$\dot{V}O_2max$ ($l \bullet min^{-1}$)	$\dot{V}O_2max$ ($ml \bullet kg^{-1} \bullet min^{-1}$)	HRmax ($bt \bullet min^{-1}$)	Activity ($mi \bullet wk^{-1}$)
Younger (n=9)	21.2 ±2.4	173.1 ±3.8	76.3 ±6.6	1.90 ±0.08	250.2 ±12.9	14.7 ±4.9	4.036 ±0.50	52.9 ±5.2	197.2 ±5.6	4.8 ±8.0
Older (n=9)	46.4 ±4.6	179.9 ±5.7	82.2 ±9.5	2.01 ±0.12	246.8 ±15.8	16.6 ±5.5	4.169 ±0.60	51.3 ±9.2	177.7 ±9.9	24.1 ±19.7
p	<0.01	<0.05	>0.05 (p=0.17)	>0.05 (p=0.06)	>0.05 (p=0.61)	>0.05 (p=0.45)	>0.05 (p=0.69)	>0.05 (p=0.64)	<0.05	<0.05

Values are means ± SD. A_D, surface area; $A_D \bullet wt^{-1}$, surface area-to-weight ratio; $\dot{V}O_2max$, maximal oxygen uptake; BF, body fat; HRmax, maximal heart rate; Activity, weekly regular aerobic activity.

Table 2. SWEATING SENSITIVITY (SLOPE). ESOPHAGEAL TEMPERATURE AT SWEAT ONSET (THRESHOLD) AND TIME (MINUTE) OF SWEAT ONSET ON THE FIRST AND LAST DAY OF HEAT ACCLIMATION

Group	Slope ($mg \bullet cm^{-2} \bullet min^{-1} \bullet {}^{o}C^{-1}$)		Threshold (^{o}C)		Onset Time (min)	
	Day 1	Day 10	Day 1	Day 10	Day 1	Day 10
Younger (n=4)	0.50 ±0.06	0.59 ±0.02	36.99 ±0.09	36.67* ±0.08	6.67 ±1.86	2.25* ±0.48
Older (n=4)	0.47 ±0.09	0.63 ±0.10	36.79 ±0.12	36.64 ±0.07	6.25 ±1.44	2.00* ±1.00
	($p=0.78$)	($p=0.70$)	($p=0.23$)	($p=0.75$)	($p=0.86$)	($p=0.83$)

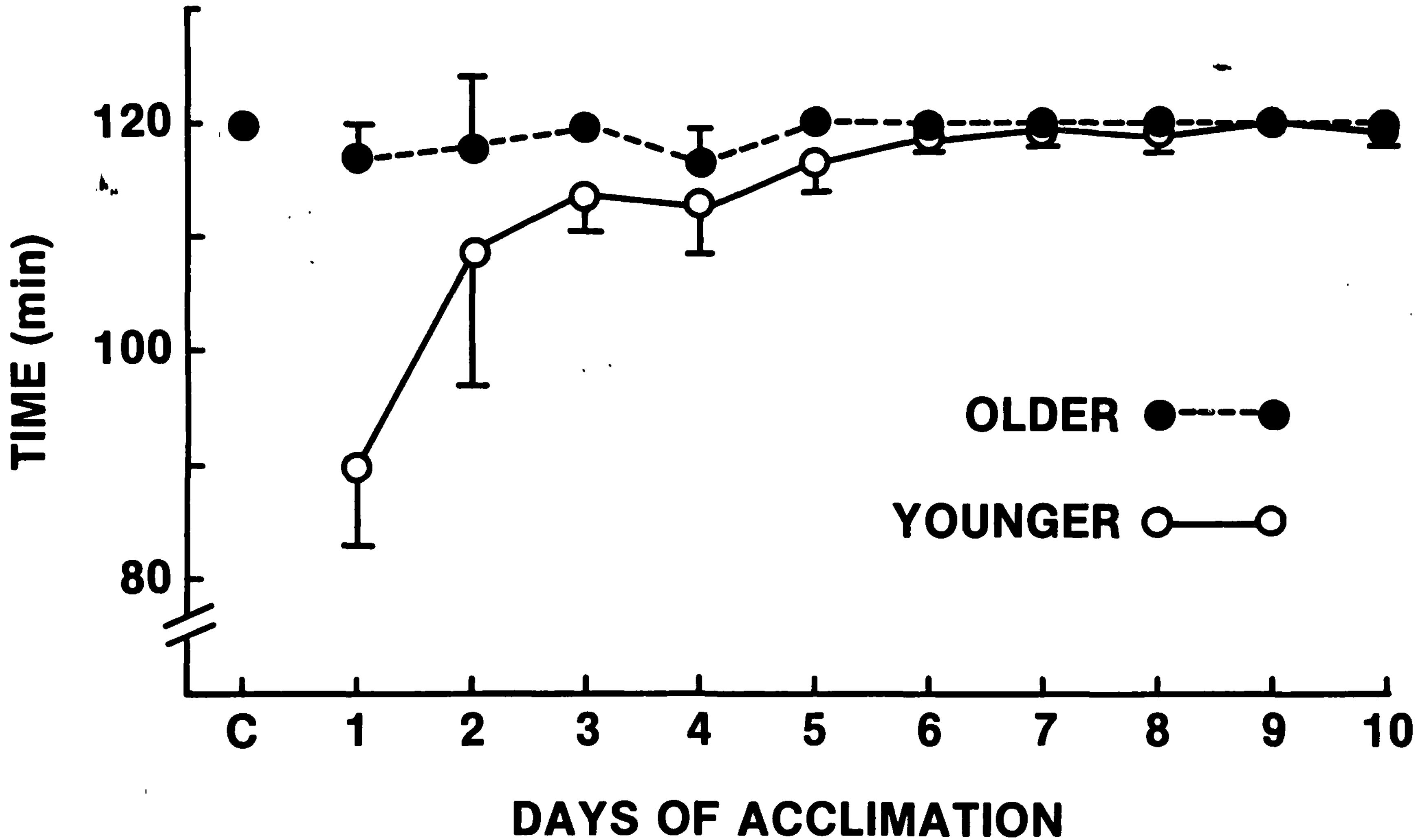
Values are means ± SE. Asterisk (*) denotes a significant difference ($p<0.05$) from Day 1 to Day 10.

Table 3. COMPARISON OF HEMATOLOGICAL DATA FOR THE YOUNGER AND OLDER MEN DURING THE FIRST AND LAST DAY OF HEAT ACCLIMATION

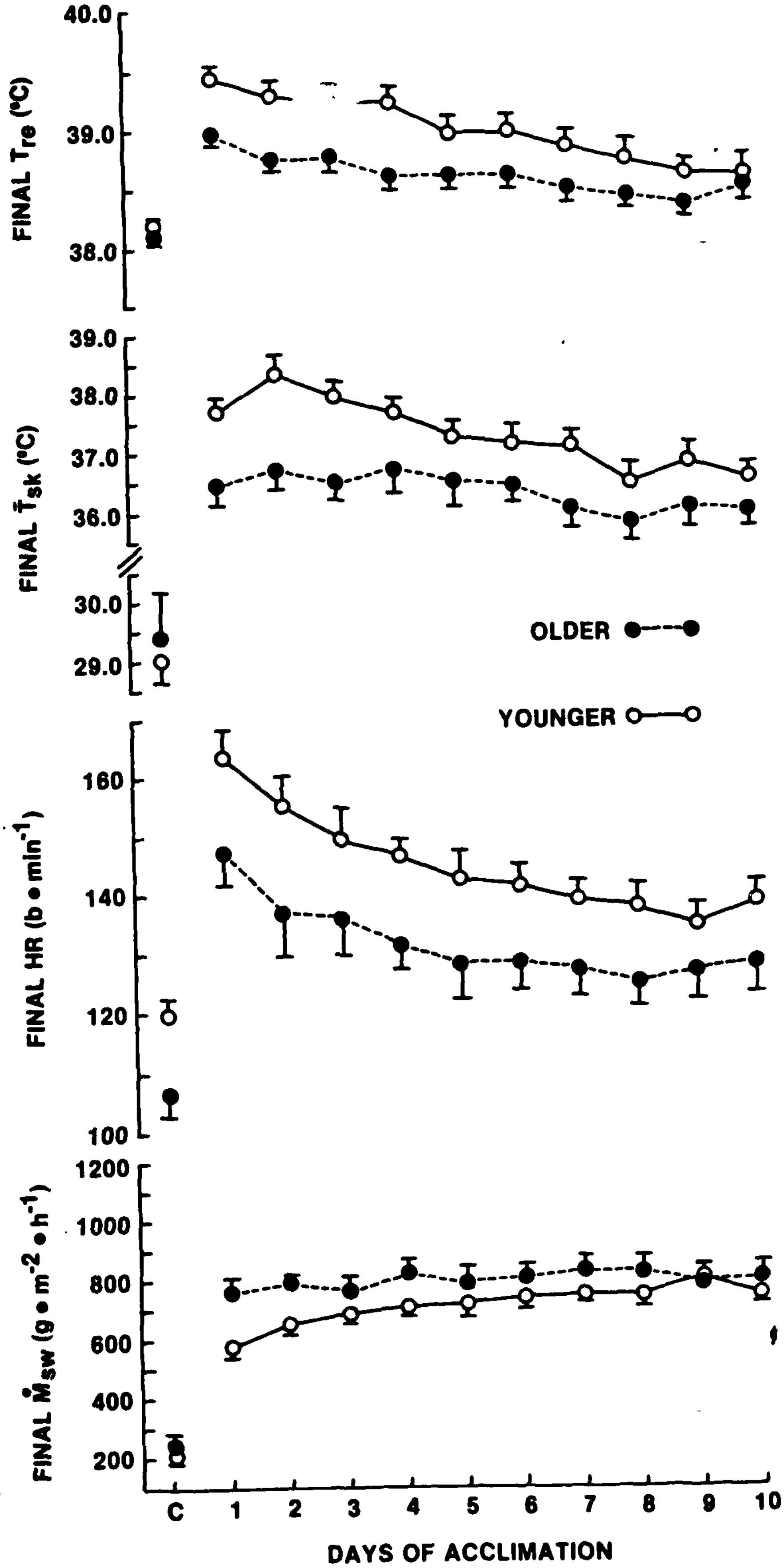
		DAY 1		Pre (D_1)-	DAY 10		Significant Differences		
		Pre	Post	Pre (D_{10})	Pre	Post	Y - O	Acclimation	Pre- Post
Plasma Volume, l	Y	3.05±0.14	3.23±0.18	—	3.29±0.14	3.41±0.15			
	O	3.36±0.10	3.47±0.12	—	3.53±0.15	3.66±0.15	NS	*D_{10}>D_1 (Pre & F	*
Total Proteins, g	Y	261±10	270±12	—	276±10	279±10			
	O	285±12	292±14	—	297±15	301±15	NS	*D_{10}>D_1 (Pre)	*D_1
ΔPV, %	Y	Base Line	7.3±2.8	8.0±2.2	Base Line	3.8±0/6			
	O	Base Line	3.7±1.5	5.1±2.6	Base Line	3.7±1.8	NS	NS	NS
Osmolality, mosmol•kg^{-1}	Y	279±1	280±1	—	279±1	277±1	*Pre (D_1)	NS	NS
	O	283±1	284±2	—	281±1	285±1	*Post (D_{10})	NS	*D_{10}
Sodium, meq•l^{-1}	Y	142.7±0.4	142.5±0.4	—	142.8±0.4	142.0±0.5	*Post (D_1)	NS	NS
	O	143.5±0.4	144.5±0.5	—	143.4±0.4	145.0±0.5	*Post (D_{10})	NS	NS
Potassium, meq•l^{-1}	Y	4.4±0.1	5.1±0.1	—	4.3±0.1	4.9±0.1			
	O	4.5±0.1	5.1±0.1	—	4.4±0.1	5.0±0.2	NS	*D_{10}>D_1 (Pre & Post)	*

Values are means ±SE for 1st and 10th days of the acclimation period (D_1 and D_{10}) and the difference between pre-exposure on Day 1 and pre-exposure on Day 10 (Pre (D_1) -Pre (D_{10})) for the young men (Y) and old men (O) both pre-exposure (Pre) and post-exposure (Post). ΔPV, change in plasma volume. In the significant differences columns; *=$p<0.05$; $D_x>D_y$: values for D_x are significantly ($p<0.05$) higher than those of D_y; Y-O, difference between young men and old men; NS, not significant.

Fig. 1

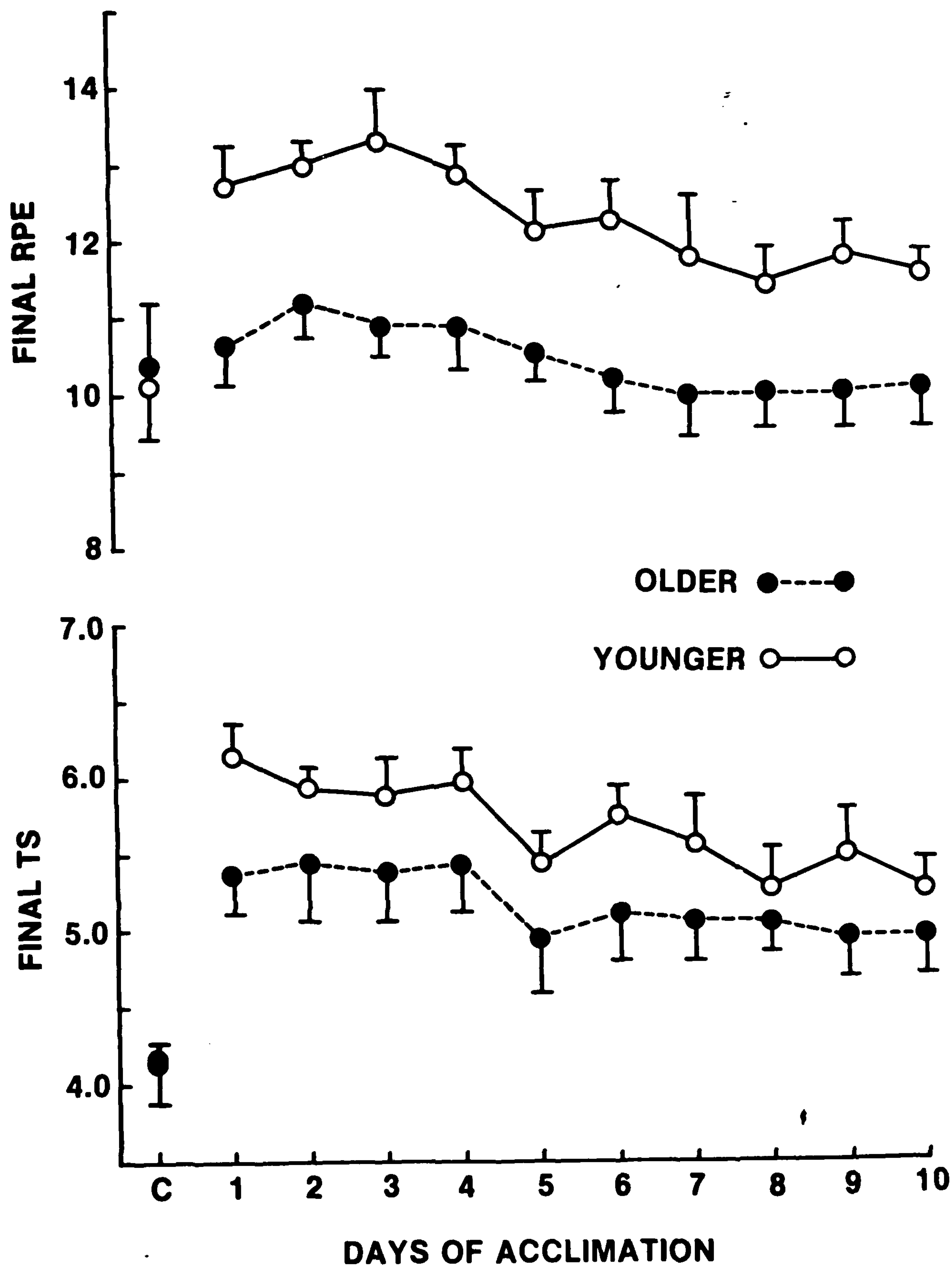


TIME (min)
120
100
80
C
1
2
3
4
5
6
7
8
9
10
DAYS OF ACCLIMATION
OLDER
YOUNGER



FINAL T_{re} (°C)
40.0
39.0
38.0
FINAL $\bar{T}_{sk}$ (°C)
39.0
38.0
37.0
36.0
30.0
29.0
OLDER
YOUNGER
FINAL HR ($b \bullet min^{-1}$)
160
140
120
100
FINAL $\dot{M}_{sw}$ ($g \bullet m^{-2} \bullet h^{-1}$)
1200
1000
800
600
400
200
C
1
2
3
4
5
6
7
8
9
10
DAYS OF ACCLIMATION

Fig.2



14
12
10
8
FINAL RPE
OLDER
YOUNGER
7.0
6.0
5.0
4.0
FINAL TS
C
1
2
3
4
5
6
7
8
9
10
DAYS OF ACCLIMATION

Fig. 3

END

DATE

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1988